ENHANCED FS-ALOHA (E-FS-ALOHA) ALGORITHM FOR CONTENTION RESOLUTION IN WIRELESS ATM SYSTEMS

A Thesis Submitted

in Partial Fulfillment of the Requirements

for the Degree of

Master of Technology

by

Deepak Kumar Sood

to the

Department of Electrical Engineering
Indian Institute of Technology, Kanpur
February 2001

Certificate

This is to certify that the work contained in this M Tech thesis entitled **Enhanced FS-ALOHA (E-FS-ALOHA) Algorithm for Contention Resolution in Wireless ATM Systems,** by Mr Deepak Kumar Sood (Roll No. 9910428) has been done under my supervision and that this work has not been submitted elsewhere for a degree

Vishwanath Sinha,
Professor,
Dept of Electrical Engineering,
Indian Institute of Technology,
KANPUR- 208 016.

Dedicated to
My Parents and Brother

Acknowledgments

I express my deepest sense of gratitude to my thesis supervisor Dr. V Sinha for his guidance and the encouragement he has provided throughout my thesis work No words will be adequate to quantify his patience and understanding I would also extend my thanks to my teachers Dr A K Chaturvedi, Dr. R K. Bansal, Dr Y N. Singh, and Dr. S Umesh who have introduced me to various courses during my academic program.

I am thankful to my friends Anil, Bhoomika, and Sasi for their interest in my thesis work and for helpful discussions I had with them I am also thankful to my friends Babu, Amit, Venu, Raju, Satyendra, Pradeep, and Srilakshmi for maintaining a wonderful work environment in the lab and for giving me valuable suggestions I would like to give special mention to my friend Sachin The countless hours spent with him were a great respite from the hectic schedule here. I am also thankful to Mr Vivek and Mr. Vineet for providing me various kinds of help in the ernet lab during the course of my thesis work.

Words are not enough to express my feelings towards my Parents and my Brother I always found them standing by my side during my hard days They have always been the constant source of inspiration for me

Finally, I would like to pay my heartfelt thanks and prayers to the God, without whose grace, my thesis would have not seen, the light of the day

Deepak Kumar Sood

Abstract

In wireless network, the broadcast nature of the radio channel requires the introduction of a Medium Access Control (MAC) layer, in order to coordinate the access to the shared radio channel A MAC protocol should not only avoid collision and distribute the available bandwidth in an efficient way, but should also support QoS provisioning. The delay experience on the contention period of the MAC frame has major impact on the delay performance of the MAC protocol, hence a delay efficient Contention Resolution Algorithm is required to satisfy the QoS contract

This thesis presents a Collision Resolution Algorithm, denoted as Enhanced FS-ALOHA (E-FS-ALOHA). This algorithm is used to inform the Base Station about the bandwidth needs of the Mobile Stations in a Wireless ATM network. E-FS-ALOHA is based on original FS-ALOHA algorithm, which groups the requests arrived at the mobile terminals during a frame length and serves these groups (Transmission Sets) on a FIFO basis using slotted ALOHA. The efficiency of FS-ALOHA decreases with the total number of slots assigned for contention mechanism In the proposed algorithm the overall performance (throughput and delay) of FS-ALOHA is further improved by serving two sets at a time instead of just one (as in FS-ALOHA) over the total contention period Only when the number of available contention slots are less (i e no of contention slots less than six) the maximum throughput achieved by E-FS-ALOHA is somewhat lower than the one attained by the FS-ALOHA. However the delay performance of E-FS-ALOHA is always superior to FS-ALOHA. The complexity of E-FS-ALOHA is comparable to that of FS-ALOHA, but is requires no additional transmission bandwidth for its operation as compared to FS-ALOHA The performance of E-FS-ALOHA is analyzed via simulation

Contents

List of Figures and Tables

List of Acronyms

ABR	Available Bit Rate
ACTS	Advanced Communication Technologies and Services
ATM	Asynchronous Transfer Mode
AWACS	ATM Wireless Access System
BER	Bit Error Rate
BRAN	Broadband Radio Access Networks
BS	Base Station
BQCA	Balanced Queue Cycles Access
CBR	Constant Bit Rate
CDMA	Code Division Multiple Access
CRA	Contention Resolution Algorithm
CRC	Cyclic Redundancy Check
CSMA	Carrier Sense Multiple Access
DSA	Dynamic Slot Allocation
E-FS-ALOHA	Enhanced FS-ALOHA
ETSI	European Telecommunication Standards Institute
FAFS	Fair Access Fair Scheduling
FCFS	First Come First Served
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FIFO	First In First Out
FS-ALOHA	FIFO by Sets ALOHA
FTR	First Transmission Rule
LAN	Local Area Network
MAC	Medium Access Control
MASCARA	Mobile Access Schemes Based on Contention and Reservation for ATM

MAN	Metropolitan Area Network
MT	Mobile Terminal
PDU	Protocol Data Unit
PRMA	Packet Reservation Multiple Access
PRMA/DA	PRMA with Dynamic Allocation
QoS	Quality of Service
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TS	Transmission Set
TS_M	Transmission Set with Sequence Number M
UBR	Unspecified Bit Rate
VBR	Variable Bit Rate
WAN	Wide Area Networks
WAND	Wireless ATM Network Demonstrator
WATM	Wireless ATM

Chapter 1

Introduction

Mobile communications has been a dominant trend in telecommunications during the last decade. A large fraction of the mobile networks carry voice-only traffic at low bit rates, but there is an increasing interest of extending the wired multiservice networks to the wireless environment Wireless ATM (WATM) seems to have the potential to offer higher bandwidth and Quality of Service (QoS) guarantees for the support of (real-time) multimedia communications, because of its fast switching techniques and the provision of different traffic classes The dominance of ATM as a backbone technology contributes to the WATM effort, towards an all-ATM network infrastructure However, this effort is in its infancy, and has to face several hurdles due to the individual characteristics of the radio medium ATM was designed for networks with high bandwidth and low bit error rate (BER < 10^{-9}). But for the wireless networks bandwidth is scarce (limited by the radio spectrum) and bit error rate is high (BER > 10^{-3}) The ATM payload is relatively small, therefore, the addition of a single byte in the header will greatly affect wireless channel throughput efficiency

1.1 Motivation and Objectives

In wireless network, the broadcast nature of radio channel requires the introduction of a Medium Access Control (MAC) layer, in order to coordinate the access to the shared radio channel among different Mobile Terminals. In case of WATM network, a MAC protocol should not only avoid collisions and distribute the available bandwidth in an efficient way, but should also support QoS provisioning. We can divide the MAC protocol function into two components· first Contention Resolution Algorithm

(CRA) to be used to inform the Base Station (BS) about the bandwidth requirements of the Mobile Terminals and second Bandwidth Allocation Algorithm to be used by the scheduler at the Base Station to distribute the available bandwidth to different Mobile Terminals to send their data packets

In an integrated services environment the Contention Resolution Algorithm used in the contention period may have a major impact on the QoS provisioning as well as the overall system performance The use, that a given connection makes of the contention period, will strongly depend on the traffic characteristics: a Constant Bit Rate (CBR) connection might never use the contention period, while the bursty nature of Variable Bit Rate (VBR) traffic makes it prone to a continuous oscillation between periods where the bandwidth needs are simply piggybacked and periods where the contention period will be used. In these situations, a delay-efficient Contention Resolution Algorithm is needed in order to comply with the QoS contract, as the access delay will be a multiple of the frame (uplink frame in FDD systems/MAC frame in TDD systems) duration The schemes used in most of the protocols like DSA++ [1], MASCARA [2](WAND Project), PRMA/DA [3], FAFS [4] etc. are slotted ALOHA or splitting algorithms

The objective of this thesis is to design a Contention Resolution Algorithm for its implementation during the contention period of MAC frame allowing an efficient transmission of the requests for capacity from the Mobile Terminals (MTs) to the Base Station. This algorithm is implemented by modifying an already proposed Contention Resolution Scheme for WATM called FS-ALOHA [5].

1.2 Structure of the Thesis

Chapter 2 starts with the background of MAC protocols for WATM The basic WATM network architecture is described next. Then general MAC protocol description for WATM network is presented. The importance of Contention Resolution Algorithm in MAC protocol operation is highlighted. Current research in this area is described next Chapter concludes with the description of FS-ALOHA algorithm, on which our work is based

In chapter 3, motivation for the improvements of FS-ALOHA is first described Then modifications in the FS-ALOHA algorithm is described resulting in Enhanced FS-ALOHA (E-FS-ALOHA) algorithm

Simulation results in terms of throughput of contention period and delay experienced by capacity requests are presented in chapter 4 These results are compared with original FS-ALOHA algorithm We show that our proposed algorithm outperforms the FS-ALOHA algorithm

Finally conclusions and future work are discussed in chapter 5

Chapter 2

Wireless ATM MAC Protocol Overview

In this chapter general MAC protocol description for WATM network is given. The importance of Contention Resolution Algorithm in MAC protocol operation is described. An already proposed algorithm named FS-ALOHA, which is used for contention period of WATM MAC protocol, is also described.

2.1 Medium Access Control in Wireless ATM

In wireless cellular ATM networks, an advanced MAC protocol is required, which is able to provide support to all ATM traffic classes defined by ATM standards, together with efficient use of the scarce available radio bandwidth shared by all the MTs in a cell. Additionally, this protocol should be adaptive to frequent variation in channel quality.

The protocols for the radio interface of wireless ATM networks could be based on frequency division multiple access (FDMA), code division multiple access (CDMA), time division multiple access (TDMA), or combination of these techniques. In wireless ATM networks, the lack of available frequencies and the requirements for dynamic bandwidth allocation, especially for the variable-bit-rate connections, make the use of FDMA inefficient. On the other hand, as per [21], CDMA limits the peak bit rate of a connection to a relatively low value, which is a problem for a broadband application (>2 Mb/s). Accordingly, most protocols in this area use an adaptive TDMA scheme (Also hybrid TDMA/CDMA schemes are issue of current research), due to its ability to flexibly accommodate a connection's bit rate needs by allocating more or fewer time slots

depending on current traffic conditions. Beyond this general choice of a TDMA-based scheme, the MAC protocols proposed in the literature differ in the technique used to build the required adaptivity in the TDMA scheme. The two main techniques used are reservation based MAC protocols and polling based MAC protocols.

Reservation based MAC Protocols

This technique consists of reservation/allocation cycles. It dynamically allocates the available bandwidth to connections based on their current needs and traffic load. A well designed protocol of this group can be found in [6] It is a TDMA-TDD protocol, where time is divided in constant length frames and every frame is subdivided into a request period and a data period The request period is accessed by the MTs through a simple slotted-ALOHA protocol, in order to declare their transmission needs while the data period is used for actual data transmission The allocation of data slots is performed by the BS based on a Bandwidth Allocation Algorithm, and MTs are informed about the slot allocation through broadcast messages This kind of protocol are more complex and introduce some extra delays due to required reservation phase, but, on the other hand, they are stable under a wide range of traffic loads and can guarantee a predictable QoS, an important parameter in wireless ATM networks Also reservation protocols have better throughput (less overhead) and MTs can perform other functions while waiting for their transmission or reception time slots However, since slot allocations are done in advanced, it allows less flexibility in packet scheduling compared to polling protocols where instantaneous decision can be taken (i e retransmission of an important packet, new high priority request etc.)

Polling based MAC Protocols

In a polling system, the Base Station sequentially polls users for data transmission privileges. In some systems, users are polled both for request and data transmissions, while in other systems requests are sent using a random access protocol. Compared to reservation based protocols these protocols are simpler, since there is no reservation phase, but their performance depends on the algorithm that determines the polling period for each connection If the polling period is shorter than needed, they might suffer from low utilization since many slots will be empty On the other hand, if the polling period is

longer than needed, they result in increased delays and poor QoS The poll signal can be used to set parameters of anti-fading devices (antenna weights, equalizer coefficients etc) which can help to increase the link quality and therefore the channel capacity. However, the efficiency is reduced by the time wasted for poll signal transmissions. Furthermore, the mobile must listen over the channel most of the time to hear its poll Little time is thus available for power saving or channel scanning

For uplink and downlink transmissions, there are two methods of Duplex transmissions.

- Frequency Division Duplex (FDD)
- Time Division Duplex (TDD)

In FDD systems, uplink and downlink traffic are transmitted over separate channels (using different frequency bands) The total available allocation for uplink and downlink connections is determined by the frequency band attributed to both components. It is therefore easy to manage co-channel interference in a FDD system However, this frequency allocation is static while bandwidth requirements for uplink and downlink ATM connections are dynamic It is thus clear that FDD is not suitable for a WATM network In TDD systems uplink and downlink traffic time share a single frame TDD provides better flexibility in controlling the available bandwidth by dynamically allocating the length of each period Hence it can dynamically adapt to the instantaneous connection requirements Furthermore, since we have a short propagation time, guard time needed for a TDD system is short. TDD also offers the advantage that a uplink channel have the same radio propagation characteristics (fading, delay, etc.), which is not the case with FDD. Thus, for example, anti-fading information (equalizer coefficients, directional antenna weights, etc.) gathered on the uplink can also be used for the downlink transmission. Therefore, TDD is preferable for a WATM network

2.2 Architecture of WATM Networks

The architecture proposed by most researchers is composed of a large number of small transmission cells, called pico cells. Each pico cell is served by a Base Station.

All the Base Stations in the network are connected via the wired ATM network. The use of ATM switching for intercell traffic also avoids the crucial problem of

developing a new backbone network with sufficient throughput to support intercommunication among large number of small cells The mobile units in the cell communicate with only the base station serving that particular cell, and not with other mobile units directly The BS also provides the gate for wired ATM networks to access the wireless ATM network The main function of the BS is to relay ATM cells back and forth to the wired and wireless networks

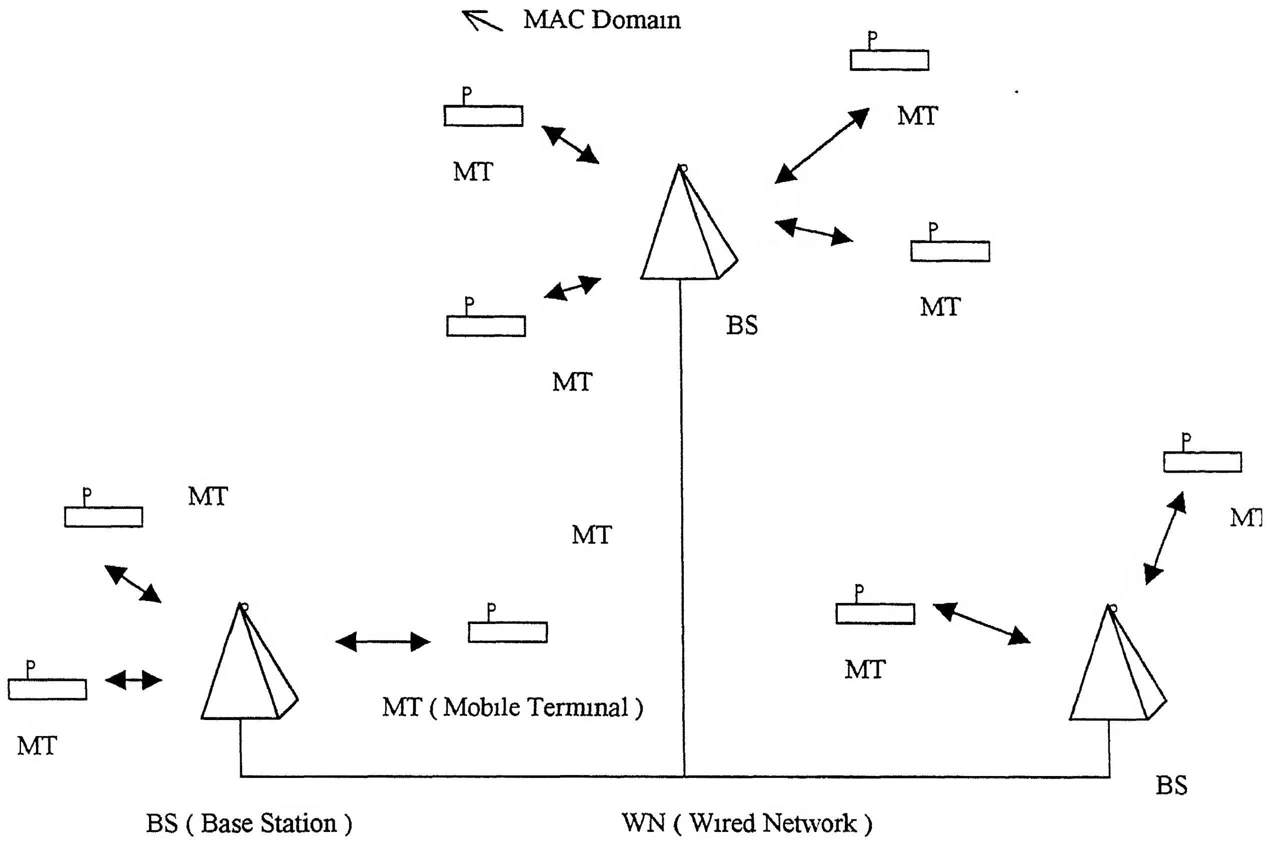


Fig 2.1·Architecture of the system

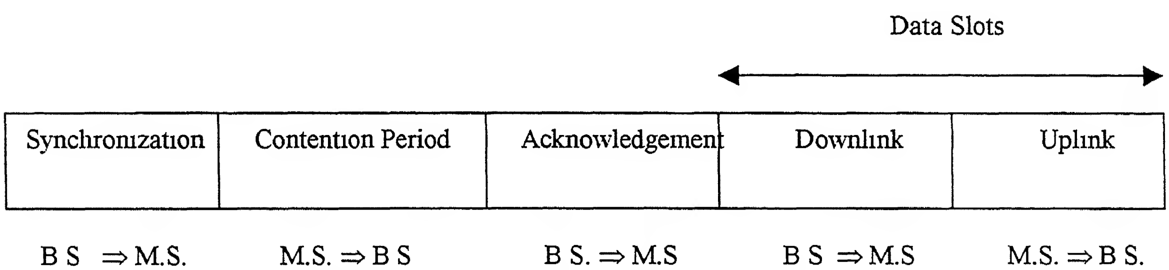
The radio channel is time slotted with slots long enough to contain an ATM cell pay–load plus the overhead for the MAC and Physical layers Slots, grouped in frames of fixed duration, are used for the uplink (from Mobile Stations to Base Station) and downlink (from Base Station to Mobile Stations) transmission according to the TDMA-

TDD technique and are dynamically assigned frame by frame The format of the frame is discussed in next section The length of each field (discussed in next section) can change frame by frame, under the control of the MAC scheduler at the BS

2.3 Typical MAC Frame

The MAC frame is generally divided into five fields synchronization, contention, acknowledgement, uplink data and downlink data Field boundaries are variable in nature A typical MAC frame is shown in figure 2.2.

Synchronization period is used to synchronize the Mobile Terminals with the Base Station For variable boundaries MAC frame, it is also used to inform mobiles about these boundaries. *Contention period* is used by the Mobile Terminals to send their channel access request to the Base Station *Acknowledgement period* is used by the Base Station to inform the Mobile Terminals about the successful contentions and their subsequent position in data slots for transmission and reception *Data slots* are used for actual transmission of data.



B.S ⇒ M.S. : From Base Station to Mobile Station

M.S ⇒ B S. :From Mobile Station to Base Station

Fig. 2.2: Typical MAC frame

2.4 Basic MAC Operation

As discussed in the section 2.1 uplink and downlink data transmission periods of MAC frame are segmented into fixed size slots called data slots Contention period is also segmented into fixed size slots called minislots, duration of one minislot is smaller

than a data slot$ Several minislots can be concatenated in order to form a data slot while one contention slot maps into one minislot Data slots containing subscriber data packets are assigned to Mobile Terminals by reservation. In other words Mobile Terminals, that have data packets to send, first request the BS for bandwidth allocation and only when BS grants their requests by reserving data slots for them to send data packets, actual transmission of data takes places. Data traffic is carried via ATM cells The MAC layer appends additional bytes (MAC cell header, CRC etc) to each ATM cell in order to form a MAC packet data unit (PDU). Contention slots carry MT's request for bandwidth in "shared" or contention mode These requests contain mobile identifier number, queue conditions at the mobile buffer, type of connection (CBR, VBR, UBR, and ABR) etc Since more than one MT can transmit a request at the same time, resulting in a possible collision, a Contention Resolution Algorithm (CRA) must be implemented as part of the MAC protocol A Bandwidth Allocation Algorithm running at the Base Station controls the number of contention slots and data slots contained in a MAC frame The Base Station also decides on the distribution and location of the contention slots and data slots in a MAC frame Contention slots can be either be grouped together in clusters or distributed over the MAC frame The information about the contention/data slot location is sent to the Mobile Terminals in an appropriate period of MAC frame

The basic MAC operation is as follows Upon arrival of the first data packet, a MT sends a request packet in a contention slot that conforms to the First Transmission Rule (FTR) (FTR, which governs the access of newcomer stations, is discussed in detail in next section) Then the station waits for the request feedback from the base station If more than one station sends a request in the same contention slot, a collision results. Requests are then retransmitted according to a collision resolution algorithm Feedback about collisions must be provided by the Base Station either explicitly or implicitly. In case of a successful request transmission, the MT waits for a data grant in order to send its data. At this point if the station has additional requests for bandwidth it may choose to bypass the contention process and use the External Bandwidth Request field available in the PDU This is known as "piggybacking" In order to allocate data slots, the base station uses an appropriate Bandwidth Allocation Scheme, taking into account of different priorities and delay requirements of data packets

2.5 Contention Resolution

Contention resolution algorithms were subject of much interest in the early 1970s for the usage in packet radio transmission especially during the development of the ALOHANET project [7] Since then, much research has been devoted to devising efficient contention resolution mechanisms for multiaccess media for local area networks (LANs), metropolitan area networks (MANs), satellite networks and radio networks

Many strategies that have been developed to solve the generic problem of having two transmitters sending packets simultaneously can be divided into two basic schemes. One is the "free-for-all," similar to the one used for the ALOHANET, in which nodes attempt to retransmit collided messages hoping for no interference from other nodes [8]. A variation of this technique known as p-persistence, associates with each slot a transmission probability, p, usually controlled by the Base Station. Hence collided requests are retransmitted with a probability p. This process is repeated until a request is successfully received at the Base Station The other scheme consists of splitting collided nodes into a tree structure In this tree based mechanism [9], all nodes involved in a collision split into a number of subsets. The first subset transmits first, followed by the second subset, then the remaining subsets. The chances of future collisions are reduced by forcing stations that collided in the same slot (assuming slotted frame structure) to retransmit their requests in different slots in the future (thus distributing the number of contending stations over several slots).

These two basic schemes have evolved to adapt to various network environments and constrains. Unlike Carrier Sense Multiple Access (CSMA) techniques, which are used where the ratio of propagation delay to packet transmission time is relatively small (<< 1) and the stations can monitor the transmission channel, reservation (request/grant) techniques are used by the wireless networks. Also in order to further increase the throughput of the MAC protocol, data slots intervals are kept rather long and mini slots (the ratio of contention to data packets is typically 1/3 for WATM networks) are used to reserve noncontending slots (data slots) for sending data. Thus, only short slots are wasted by idles or collision leading to a better overall channel efficiency

The key functions provided by a CRA consist of

1 Controlling the transmission of new requests by means of the FTR

2 Giving collision feedback

3 Managing retransmissions

The FTR regulates when a newcomer station is allowed to send its first request on the contention period A feedback message informing the station about the status of its reception at the Base Station is associated with each contention slot The status of contention slot can be empty, successful, or collided, depending on whether there is zero, one, or more stations transmitting in it Finally a mechanism is needed to resolve collision and control the retransmission of request packets

First Transmission Rule (FTR)

Now we briefly discuss two strategies to control the admission of the newcomer stations These strategies, also called first transmission rules (FTRs), define in which minislot a station with a desire of connectivity is allowed to send a request FTRs can be classified as follows·

1 *Free Access* the first transmissions of requests are allowed in the same minislots used to retransmit collided requests New requests are mixed with "old" or retransmitted requests So there is no distinction between a new request and a retransmitted request

2. *Blocked Access*: new requests are not allowed on the minislots used to resolve current collisions. This is illustrated by a contention interval that is split into two regions One is reserved for ongoing collision resolution and another, denoted as newcomer minislot region, is open for new requests.

Furthermore, different strategies can be applied to each mode. For example, the Free Access mode can either be persistent or nonpersistent.

The FS-ALOHA algorithm (to be described in section 2 7) is of Blocked Access type, and the algorithm proposed by us i.e E-FS-ALOHA is a hybrid scheme consisting of both Free Access and Blocked Access mechanisms

2.6 Current Research

To make the utilization of wireless resources efficient and to ensure guaranteed quality of service (QoS), a suitable MAC protocol must be specified for the ATM air interface. Numerous proposals and standardization activities for this kind of MAC have been started during recent years. One of these, still ongoing activities, originally started as a wireless ATM (WATM) standardization initiative, is the HIPERLAN/2 system, and is currently under standardization by the ETSI (European Telecommunication Standards Institute) project BRAN (Broadband Radio Access Networks) [10], [11]. The basis ideas of reservation-based HIPERLAN/2 MAC have been derived from the DSA++ protocol [12], [13]. Another interesting protocol is MASCARA (Mobile Access Schemes based on Contention and Reservation for ATM), used in the MAGIC WAND (Wireless ATM Network Demonstrator) project within the European Union ACTS (Advanced Communication Technologies and Services) initiative [2], [14]. Other MAC protocols, which deserve to be mentioned, are the BQCA (Balanced queue cycles access) [15], and AWACS (ATM Wireless access system), used in European HIPERLINK [16], a wireless indoor backbone.

The MAC protocols differ mostly in their contention policy and the bandwidth allocation algorithm. Many Contention Resolution Algorithm are proposed for WATM networks (generally slotted ALOHA based or splitting algorithms) [5], [17], [18] etc.

2.7 FS-ALOHA Algorithm

In this section the operation of the original FIFO-by-Sets ALOHA (FS-ALOHA) [5] is described. Let us assume that from the L slots of the fixed length MAC frame, C slots ($C \leq L$) will be used for contention resolution. If a slot contains k minislots, a maximum number of $T = k \times C$ requests can be transmitted during a frame period. As the scope of FS-ALOHA only involves the contention period, from here on a *slot* refers to the time needed to transmit a request in the contention period.

In slotted ALOHA systems, an MT with a pending request will randomly choose one out of the T possible slots to send its request in the hope that no other MT will choose the same slot. FS-ALOHA, on the contrary divides the T slots of the contention

period into two disjoint sets of S and N slots such that S+N=T (see fig 2 3). The operation of FS-ALOHA is as follows.

- Those requests newly arrived in the system during the last frame (at different MTs) will attempt transmission for the first time randomly choosing one out of the S slots.
- If a request arrives without collision at the Base Station, it is used to schedule a future cell transmission in the Uplink Data Transmission period
- If some of these attempts are unsuccessful they are grouped into a Transmission Set (T.S), and join the queue of TSs pending to be served
- The other N slots will be used to serve the queue of backlogged Transmission Sets on a FIFO basis A Transmission Set will remain at the head of the queue until all its associated requests have been successfully sent to the Base Station

Hence the parameters of the scheme are just two

- Number of signalling slots per frame S ≥ 1 used to serve the newly arrived requests This parameter determines the TS generation rate
- Number of slots N ≥ 2 allocated to the service of the backlogged Transmission Sets in the distributed queue.

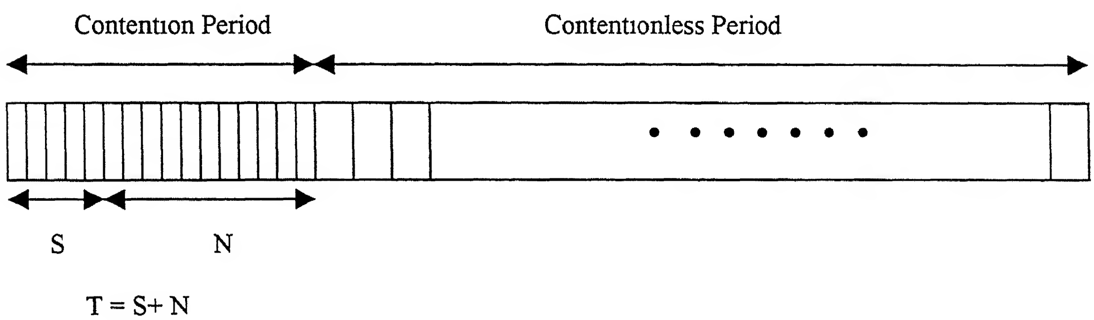


Fig 2.3: Structure of a MAC frame, fixed frame length L=30 slots, T=16 minislots, S=5 minislots, N=11 minislots, k=2

Fig 2.4 explains the operation of FS-ALOHA algorithm TSs are shown as oval boxes, with dots inside them denoting requests pending to be served, in the distributed FIFO queue Consecutive sequence numbers are assigned to the Transmission Sets in the FIFO queue In every frame i a new TS $N_G(i)$ may be generated, if not all of the requests arrived during the previous frame are successfully transmitted in the S contention slots At the same time, another TS number $N_S(i)$ is being served making use of N contention slots, so the number of TSs in the distributed queue is $N_G(i)-N_S(i)$

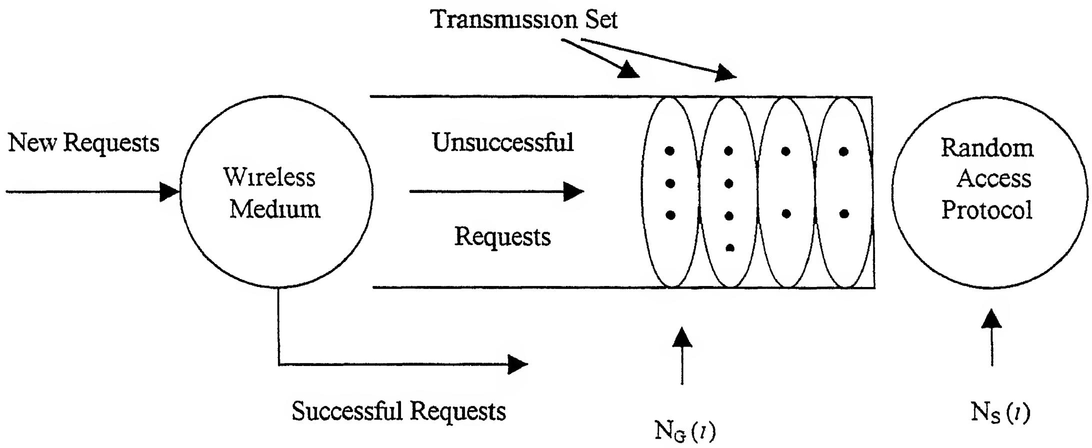


Fig 2 4: Construction of the Distributed FIFO Queue

2.7.1 Generation of the Transmission Sets

Let us assume that the system has already been initialized and the Transmission Set distribution queue is nonempty. All the mobiles with a new request for the contention channel generated during the last frame i will randomly choose one of the S contention slots to send their request packet For each of the S slots the Base Station observes one of the following situation

- There has been an error in the channel or there has been more than one request attempt (i.e an errored CRC or collision is detected)

- There has been just one request attempt (there has been activity in the channel and the CRC is correct)
- There has been no request attempt (silence in the signalling slot)

Based on these observations the Base Station takes the corresponding actions regarding the generating TS $N_G(i)$

- If neither collisions nor errors were detected in any of the S slots the TS $N_G(i)$ is not generated
- Otherwise a new Transmission Set is build and stored in the distributed TS FIFO queue (see fig 2 4)
- Passes the successful requests from the MTs to the central scheduler located at the Base Station
- Notifies the MTs whether or not a new TS was generated and which requests were successfully received This can be done by including in the Acknowledgement period of MAC frame a field of length r bits (r-bit field with r=S). Each bit in this field is associated to one of the S contention slots, and contains a 1 if a successful request was received in the slot or 0 if no request, collision or error were detected

By keeping track of the r-bit header field (see also the Implementation Issues section) the MTs can keep an image of the state of the TS distributed queue knowing at every moment how many TSs there are in it When this TS FIFO queue is empty, either right after the initialization of the network or after a period of low activity, $N_G(i)=N_S(i)$ and there are no backlogged Transmission Sets to be served using the N contention slots In this situation, the arrived packets will randomly choose one out of the total number T=N+S of slots in the contention, instead of just using the S slots. Therefore when the system is empty (i.e. no TS backlogged) the behavior of the system is identical to slotted ALOHA The detection of a collision or errored request in one of these T slots will cause the generation of a TS and the beginning of a busy period. in the next frame only the first S slots will be used for new requests and the other N to serve the Transmission Set in the queue

2.7.2 Service of the Transmission Sets

During the busy period of the system (i e. when the TS distributed queue is not empty) N out of the T=S+N slots of the contention period will be used to serve the groups formed by unsuccessful requests. This will be done on a FIFO basis. The N slots will be used by the Transmission Set at the head of the queue, frame after frame, until all its associated requests are successfully transmitted (actually only during a limited number of frames to avoid Head of the Line blocking; see the Implementation Issues section)

Assuming that the MTs have correctly built the distributed TS queue, all the mobiles with requests belonging to the TS in service will choose one out of the N slots to send their request, using slotted ALOHA algorithm. After receiving the information contained in the contention period the base station does the following:

- Hands over the successful received requests to the central scheduler, in charge for generation of the corresponding permits
- Notifies to the MTs the results by including in the Acknowledgement Period of MAC frame a field of length t bits (t-bit field with t=N), in the same way as the r-bit field, each bit in this field is associated to one of the N contention slots, and is set to 1 if a successful request was received in the slot or 0 if no request, a collision or an error were detected.

If there is a collision (at least two mobiles made the attempt in the same slot) or some request is errored in any of the N slots the service of the transmission will continue in the next frame. Otherwise, the TS is removed from the queue and the service of the next TS will be initiated in the following frame If the queue becomes empty an idle period starts, where all the slots (T) available in the contention channel are used by the new request arrivals.

During all this process the mobiles are blind to the extent that they know only about their own sent requests and without any information on collisions. The necessary feedback is provided by the t-bit field transmitted by the Base Station in the Acknowledgement period of MAC frame.

2.7.3 Implementation Issues

In this section, the issue of how the Mobile Terminals construct the right image of the distributed queue of Transmission Sets is discussed. As previously described the Base Station includes in the Acknowledgement period a field of ~~of~~ $r+t$ bits, each of them associated to one of the slots of the contention period Each bit of $(r+t)$ is set to 1 if a successful request was conveyed in the associated slot or it is set to 0 otherwise The MTs know which contention slot they have used to send their request, so by listening to the $(r+t)$-bit field they know exactly whether their request was successful or not.

For the mobile terminals to know which TS they belong to (if they could not succeed in transmitting successful requests in the last frame), Base Station also includes in the Acknowledgement period, two new fields, one containing the sequence number of the TS in generation $N_G(i)$ and the other the sequence number of the TS in service $N_S(i)$. In this way the Mobile Terminals that have experienced a collision, are able to know in which TS they belong to. And also by knowing the sequence number of TS that is currently being served all the mobile that belong to that TS will attempt retransmission in the current frame

Another problem that may arise is associated to the wireless channel capture[1][19], which may cause that one of the requests involved in a collision is nevertheless successfully received by the Base Station If just one bit per request slot in the contention period is used to indicate either success or collision, the MTs whose requests have been captured will erroneously assume that their requests were successfully received by the Base Station. A possible solution for this problem is to indicate the MAC address of the Mobile Terminal whose request has been received, thus replacing the $(r+t)$–bit field in the Acknowledgement period a field, containing (S+N) Mobile Terminal MAC addresses

Yet another problem arises when, due to the special characteristics of the wireless medium, the propagation link between an MT and the Base Station enters a state of high BER (bit error rate) which can last for several milliseconds. In this case a Head of Line blocking may appear in the temporarily bad propagation channel period many

[1] When two mobiles transmit at the same frequency (or at the same time slot) it may be that the BS receives very well the signal of one of them without detecting any interference (or collision). This is called Capture Effect

retransmissions of packets will occur causing long delays in the TSs services Due to the FCFS discipline used in the TS service, the overall network performance will fall To avoid this performance degradation, each packet will be retransmitted only a limited number of times during the service of a TS When a packet reaches the maximum limit it will be removed from the TS in service and reserved for service in the next TS If this situation remains for several TSs, the packet will be dropped

Chapter 3

Enhancement of FS-ALOHA

This chapter presents an enhancement of original FS-ALOHA, the Collision Resolution Algorithm for the Contention period of MAC frame in WATM environment. This chapter is divided into two sections After justifying the need for modifying FS-ALOHA in first section, second section presents the modifications of the basic scheme, denoted as Enhanced FS-ALOHA (E-FS-ALOHA).

3.1 Motivation for the Improvements of FS-ALOHA

The original FS-ALOHA outperforms slotted ALOHA as described in [5] One of its nicest features is its throughput stability even in highly congested situations as can be seen fig 3 1. This is explained by its grouping of capacity requests on a per frame basis, regardless of the congestion level In fig 3 1 throughputs of slotted ALOHA and FS-ALOHA are shown for a contention period of T=10 Slots. In slotted ALOHA mechanism new requests are assumed to attempt transmission with probability one and, in case of collision, reattempt transmission in subsequent frames with a persistence probability given by *ptx*.

In FS-ALOHA, the number of requests in a given TS is independent of the time required for the service of the preceding TSs, thus avoiding the typical positive feedback most Collision Resolution Algorithms experience in congestion situation (e.g blocking splitting algorithms). However, the comparative advantage of FS-ALOHA decreases with increasing values of T, the total number of contention slots available for the scheme. As the size of the contention period increases, the deployment of FS-ALOHA becomes less

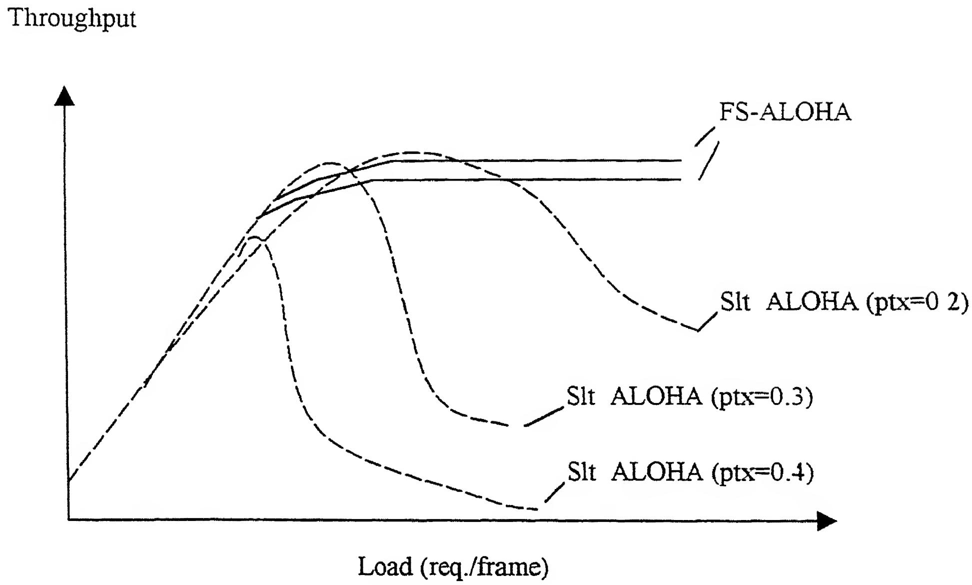


Fig 3.1. Throughput of FS-ALOHA vs Slotted ALOHA

attractive as its maximum throughput monotonically decreases with increasing T Even taking the optimal (S, N) combination, for each T, the throughput of FS-ALOHA for the cases T = 3, T = 10 and T = 20 drops from 0 42 to 0 35 and, finally, to 0 278 The reason behind this decrease in efficiency is a low utilization of S and N contention slots In pure slotted ALOHA systems with *P* slots the optimal throughput is achieved when exactly *P* transmission attempts are made Hence, when T becomes large, it could be more efficient to have (in average) more transmission attempts in T slots

3.2 Enhanced FS-ALOHA Algorithm

A different approach, in order to increase the utilization of the contention slots when T becomes large, may be to allow the simultaneous service of more than one Transmission Set, thus increasing the average number of transmission attempts in the T slots. So as opposed to the original FS-ALOHA algorithm where only one TS is served at a time in N slots and only new requests are served in the S slots, in Enhanced FS-ALOHA (E-FS-ALOHA) algorithm, two TSs are served at a time over the total contention period of length T slots, one TS is served in the S slots together with the new requests and second TS is served in the N slots These two transmission sets are consecutive TSs at the top of the FIFO distributed queue In this, there could be two

situations depending upon whether the TS that is being served in the N slots or the TS that is being served in the S slots finishes first.

Suppose Base Station places two Transmission Sets with sequence numbers M and M+1 simultaneously in the server Hence mobile nodes with requests belonging to TS with sequence number M (TS_M) will start attempting in the N slots and mobile nodes with requests that belong to TS_{M+1} will start attempting in the S slots together with the new requests A TS finishes its services when all its pending requests have made successful transmission attempts. All pending requests in both TSs continue to attempt in N or S slots of successive frames until atleast one TS finishes its service

Suppose TS_M is serviced before TS_{M+1} (all the requests in the TS with sequence number M have made successful transmission attempts, and some requests in TS with sequence number M+1 are still left to attempt in next frame). In this situation, TS_{M+1} will start attempting in N slots of successive frames, and TS_{M+2} will start attempting in S slots of successive frames, and so on for this type of situation

If TS_{M+1} finishes before TS_M (all the requests in the TS with sequence number M+1 have made successful transmission attempts, and some requests in the TS with sequence number M, are still left to attempt in next frame), then from next frame onwards the S slots will be totally devoted to the service of new requests only and TS_M will be attempting in same N slots until TS_M have finished service Thereafter BS will place next two transmission Sets TS_{M+2} and TS_{M+3} in the server and TS_{M+2} will start attempting in N slots and TS_{M+3} will start attempting together with new requests in the S slots of successive frames, and so on

The TSs are generated as in the original FS-ALOHA (on a per-frame basis) and the end of service of a TS in N slots is again marked by the lack of collisions in the N slots. For each frame Base Station will be transmitting the sequence number of TS that will be served in current frame and the next TS in the distributed FIFO queue will be attempting in S slots together with new requests In other words only sequence number of the TS that is going to be served in the N slots in the current frame is needed for the operation of the protocol. The immediately next TS in the distributed FIFO queue will be attempting in the S period together with the new requests as long as this TS is nonempty

Fig 3.2 illustrates the operation of Enhanced FS-ALOHA algorithm The state of the Transmission Set FIFO queue as well as the transmission attempts in the contention slots are depicted for six consecutive frames (frame no i to $i+5$) Transmission Sets which are attempting in current frame are denoted as shaded oval boxes (These TSs are said to be placed on the server) Backlogged TSs in distributed FIFO Queue are shown as oval boxes with solid line border Also the TS that is currently being added to the queue is shown as oval box with dotted line border. The number of requests containing in each TS is shown as dots in the corresponding oval box. Initially there are two backlogged TSs and two TSs on the server

In the i^{th} frame (fig (a)) two new requests together with three requests from TS_{M+1} attempt transmission in the S slots Due to collision experienced by one new request in the S slots, one new TS (TS_{M+4}) is forced to placed in the FIFO queue with one request and due to all three requests of TS_{M+1} experienced collision in S slots, TS_{M+1} maintains its status of having three pending requests to be served in next frame (Whether TS_{M+1} will attempt in S slots or N slots of next frame will depend upon the result of the transmission attempt of TS_M in the N slots of current frame) In the N slots both transmission attempts of TS_M are unsuccessful so TS_M maintains its status of having two requests to be served in N slots and therefore TS_M will attempt in the N slots of next frame.

In the next frame (fig (b)), five new requests together with three requests from TS_{M+1} attempt transmission in the S slots Four new requests out of five experience collision Hence one new TS (TS_{M+5}) with four requests is forced to place in the FIFO queue, and because one request out of three of TS_{M+1} manages to have successful transmission, TS_{M+1} changes its status and now it contains two pending requests to be served in the next frame. In N slots both transmission attempts of TS_M are successful, hence this TS is removed from the server. Because TS_M finishes its service in this frame, in next frame TS_{M+1} will attempt in N slots and new TS (TS_{M+2}) from the FIFO queue will be placed on the server and this TS will attempt in S slots.

In next frame (fig (c)), only one new request attempts in S slots and that is also successful. Hence no new TS is generated. All the requests present in the Transmission

Sets, TS_{M+2} and TS_{M+1} make successful transmission attempts hence these two TSs are removed from the server

In next frame (fig (d)), two new Transmission Sets TS_{M+3} and TS_{M+4} are placed on the server and make transmission attempts in N and S slots respectively Due to collision experienced by new requests, one new TS (TS_{M+6}) with three requests is forced to placed in the FIFO queue TS_{M+4} was having only one request pending and that too make a successful transmission attempt hence TS_{M+4} is removed from the server Two out of four requests of TS_{M+3} make successful transmission attempts, hence TS_{M+3} changes its status and now it contains two pending requests to be served in the next frame

In next frame, (fig (e)), due to collision experienced by new requests, one new TS (TS_{M+7}) with five requests is forced to placed in the FIFO queue Now for this frame there is no TS on the server that will attempt in S slots because TS_{M+4} finished its service before TS_{M+3} in the previous frame All requests in the TS_{M+3} make successful transmission attempts, hence this TS is removed from the server

In next frame (fig(f)) two new TS from FIFO queue are placed on the server and the procedure repeats

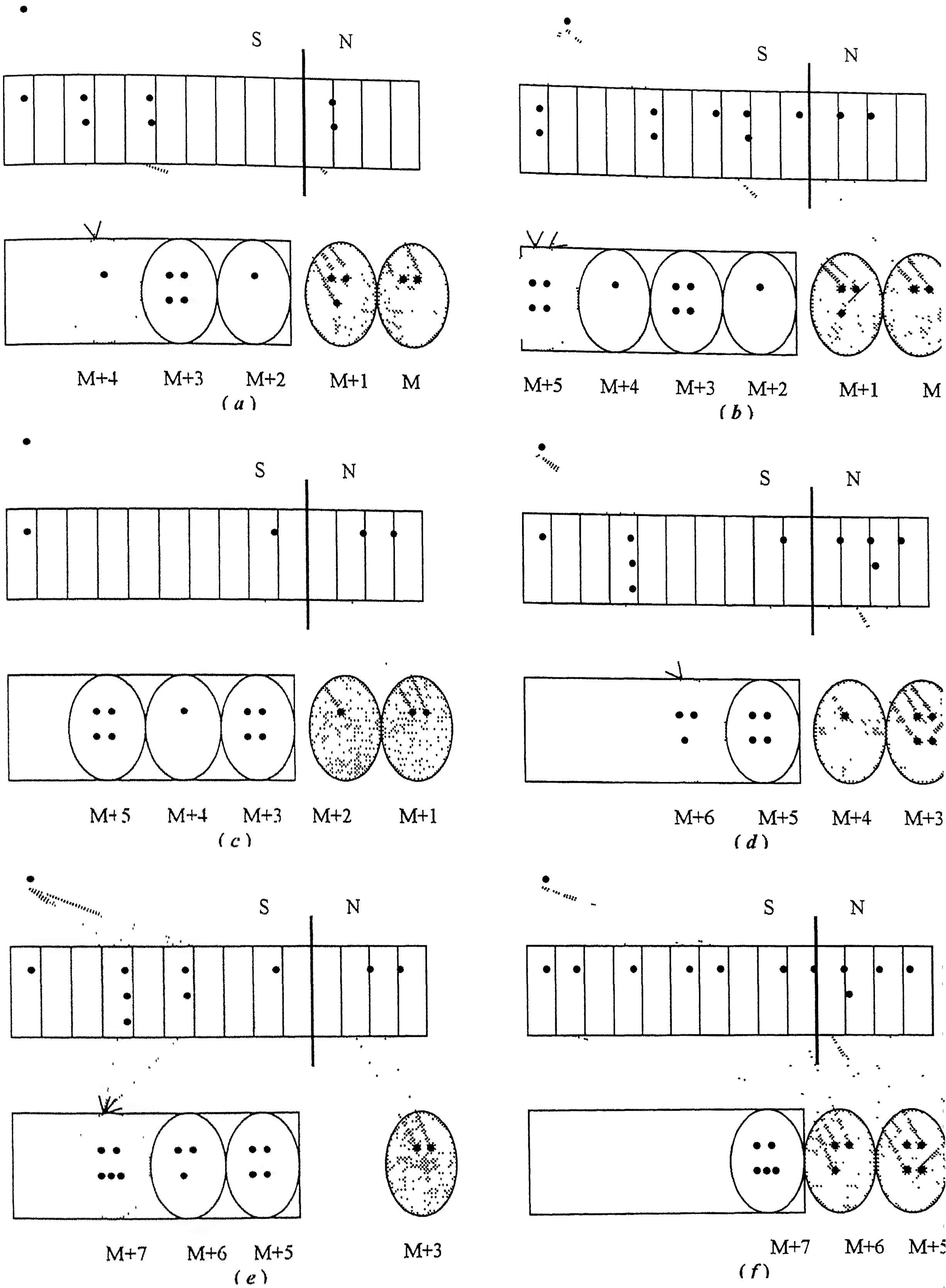


Fig 3.2 : Operation of Enhanced-FS-ALOHA , T=14, S=10, N=4
(a) i^{th} frame, (b) $i+1^{th}$ frame, (c) $i-2^{th}$ frame, (d) $i-3^{th}$ frame, (e) $i+4^{th}$ frame, (d) $i+5^{th}$ frame

Chapter 4

Simulation Results and Discussion

In this chapter, simulation results in terms of throughput and mean delay for Enhanced FS-ALOHA algorithm is presented Furthermore these results are compared with the results for original FS-ALOHA algorithm.

4.1 Simulation Results

In [5] FS-ALOHA is compared with slotted ALOHA, a scheme that has been widely implemented in the contention period of Wireless ATM systems due to its simplicity and low utilization of the contention period The complexity of FS-ALOHA is comparable to that of slotted ALOHA, but it shows much better delay performance, stability (as the throughput does not drop significantly in overload conditions), and higher maximum throughput when the size of the contention period is not too long

To compare E-FS-ALOHA algorithm with the original FS-ALOHA algorithm, we take the same simulation conditions of finite population input process as used in [5] for FS-ALOHA

The main assumptions on the input model are as follows

- The number of MTs in the network is finite and is given by the parameter M=128.
- Offered load to the system is given by the parameter λ requests arrival per frame.
- An MT with a request pending to be transmitted (backlogged) will not generate a new request until having successfully transmitted the backlogged request

Chapter 4

Simulation Results and Discussion

In this chapter, simulation results in terms of throughput and mean delay for Enhanced FS-ALOHA algorithm is presented Furthermore these results are compared with the results for original FS-ALOHA algorithm

4.1 Simulation Results

In [5] FS-ALOHA is compared with slotted ALOHA, a scheme that has been widely implemented in the contention period of Wireless ATM systems due to its simplicity and low utilization of the contention period. The complexity of FS-ALOHA is comparable to that of slotted ALOHA, but it shows much better delay performance, stability (as the throughput does not drop significantly in overload conditions), and higher maximum throughput when the size of the contention period is not too long

To compare E-FS-ALOHA algorithm with the original FS-ALOHA algorithm, we take the same simulation conditions of finite population input process as used in [5] for FS-ALOHA

The main assumptions on the input model are as follows

- The number of MTs in the network is finite and is given by the parameter M=128
- Offered load to the system is given by the parameter λ requests arrival per frame
- An MT with a request pending to be transmitted (backlogged) will not generate a new request until having successfully transmitted the backlogged request

- MTs with no backlogged requests will generate a new request in each frame with a probability $p_g = 1 - e^{-\lambda \cdot M}$

Mean delay and throughput curves for E-FS-ALOHA are presented in this section for different values of T (6, 10, 20) and different combinations of parameters S and N that give best performance in terms of delay and throughput We have simulated each experimental condition for a period of 10^8 frames

The *delay* suffered by a capacity request is defined as the time elapsed between the first transmission attempt of the request (within one frame after the generation at the MT) and its successful reception by the Base Station. *Throughput* is defined as the ratio of total number of successful transmission attempt to the total number of slots available for sending requests. As we aim only at evaluating the performance of the contention resolution scheme, we have not considered the influence of the processing time, propagation delay or errors in the wireless channel. The delay is, therefore, solely caused by the collisions in the contention period of MAC frame among the requests issued by the MTs

Figure 4 1 and 4 2 show the performance of E-FS-ALOHA when the number of available contention slots T is 6 Best cases for throughput and delay are shown for both FS-ALOHA and E-FS-ALOHA The dashed curves correspond to FS-ALOHA and solid curves correspond to E-FS-ALOHA As shown in figure 4.1 maximum attainable throughput for FS-ALOHA (for (S, N)=(3, 3)) is more than that attainable by E-FS-ALOHA (for (S, N)= (3, 3)) So far as the performance for delay is concerned both cases of E-FS-ALOHA give better performance than FS-ALOHA. *Hence for small values of T, better delay performance with E-FS-ALOHA are achieved at the expense of low throughput, as compared to FS-ALOHA.*

Figure 4.3 and 4 4 show the performance of E-FS-ALOHA when the number of available slots T is 10. As shown for E-FS-ALOHA with (S, N)=(7, 3), (6, 4) one obtains more throughput as compared to FS-ALOHA with (S, N)=(4, 6), (5, 5) Maximum attainable throughput of E-FS-ALOHA (with (S, N)=(7, 3)) and FS-ALOHA ((S, N)=(4, 6)) are 36.61% and 34.93% respectively. Again for delay performance, both cases of E-FS-ALOHA largely outperform FS-ALOHA's shown results. For low loads

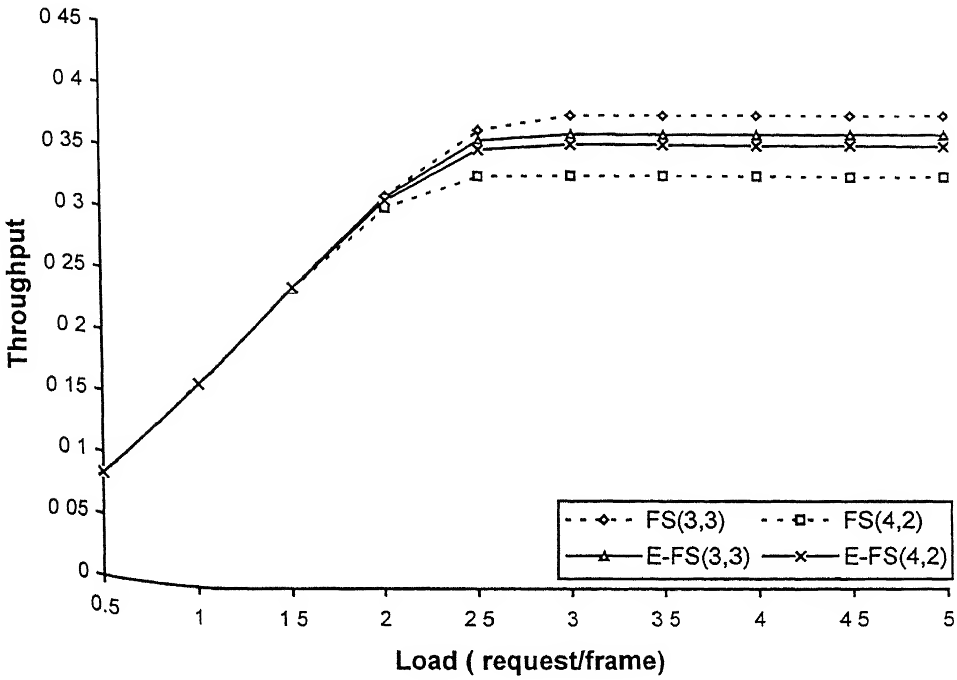


Fig 4.1 : Throughput of E-FS-ALOHA vs. FS-ALOHA (T= 6)

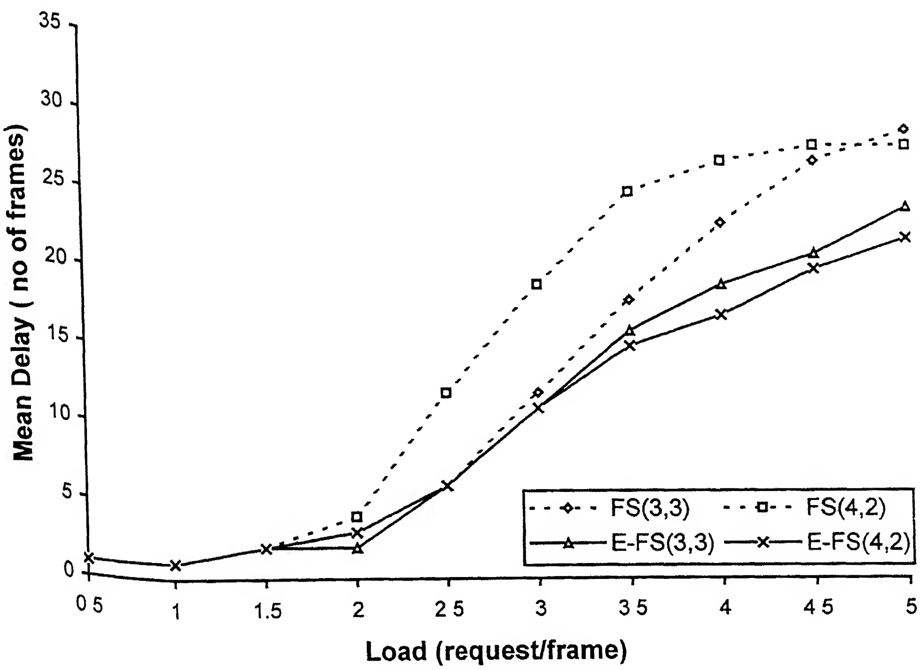


Fig 4.2 : Mean Delay of E-FS-ALOHA vs. FS-ALOHA (T= 6)

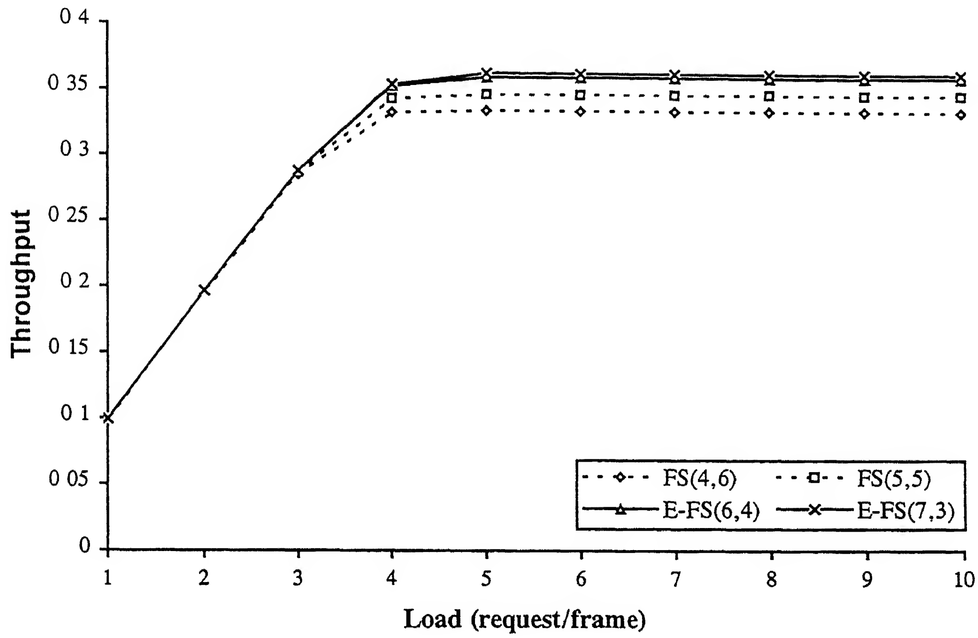


Fig 4.3 :Throughput of E-FS-ALOHA vs.FS-ALOHA (T=10)

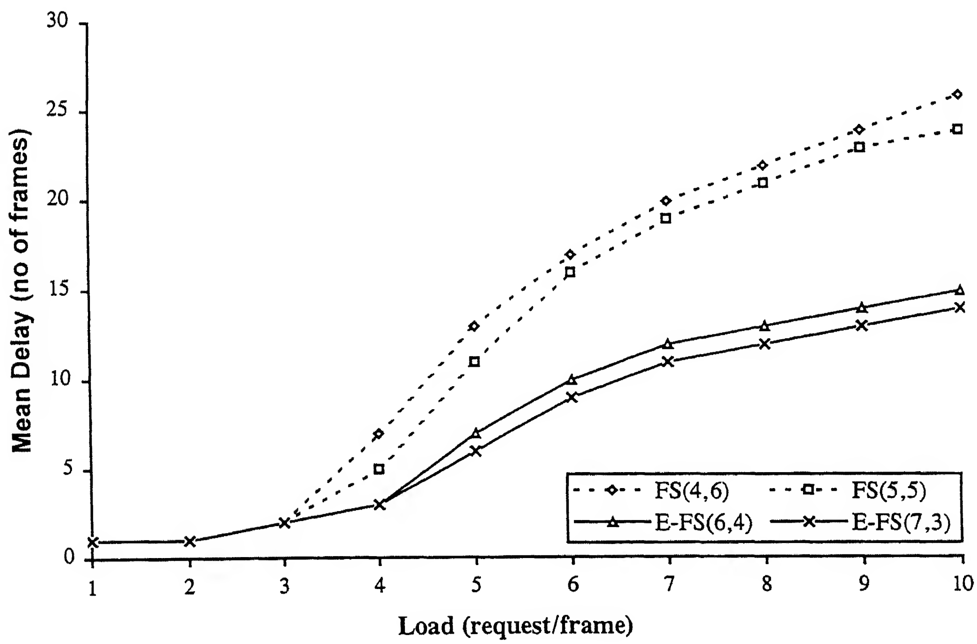


Fig 4.4 :Mean Delay of E-FS-ALOHA vs.FS-ALOHA (T=10)

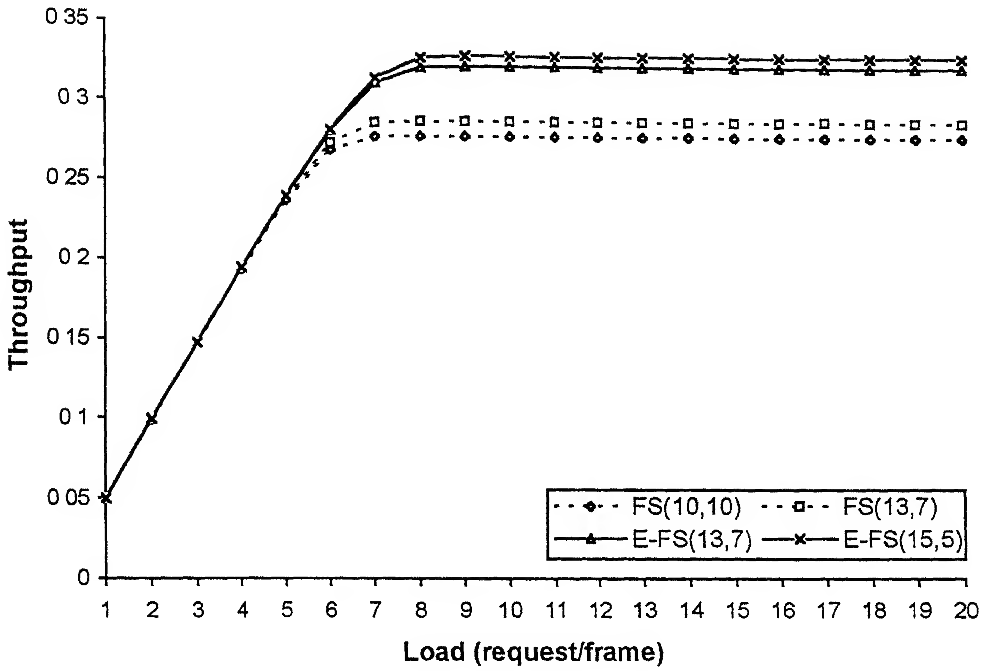


Fig 4.5 Throughput of E-FS-ALOHA vs FS-ALOHA (T=20)

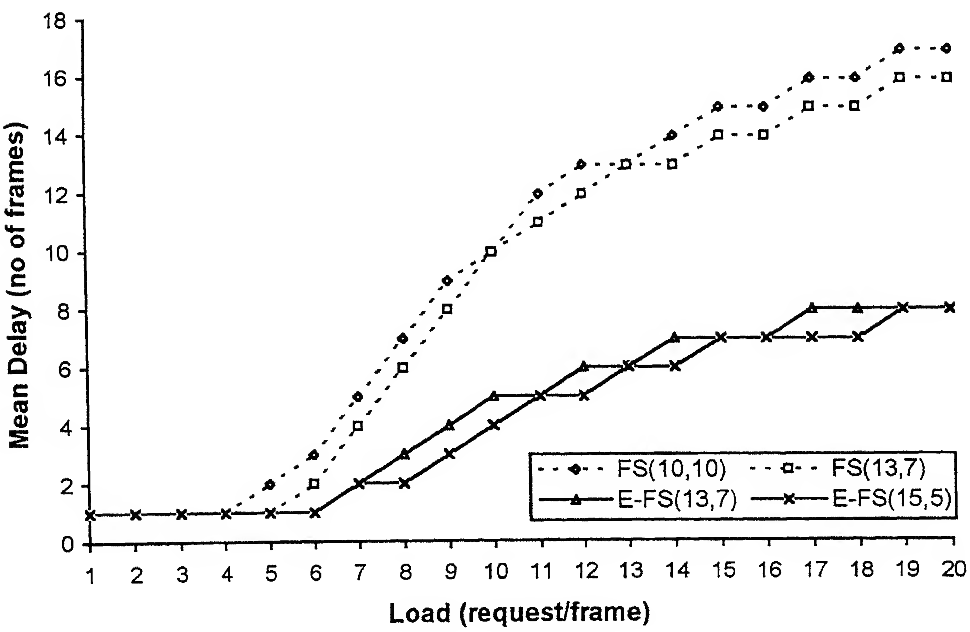


Fig 4.6 : Mean Delay of E-FS-ALOHA vs. FS-ALOHA (T=20)

(λ<3 requests/frame) both protocols behave in a similar manner in terms of throughput and delay. *Hence for T=10, E-FS-ALOHA outperforms FS-ALOHA for both throughput and delay*

Figure 4 5 and 4 6 show the performance of E-FS-ALOHA when the number of available slots T is 20 As shown for E-FS-ALOHA with (S, N)=(13, 7), (15, 5) we get more throughput as compared to FS-ALOHA with (S, N)=(10, 10), (13, 7) Maximum attainable throughput of E-FS-ALOHA (with (S, N)=(15, 5)) and FS-ALOHA (with (S, N)=(13, 7)) are 32.89% and 28 77% respectively Again for delay performance, both cases of E-FS-ALOHA largely outperform FS-ALOHA's shown results. For low loads (λ<5 requests/frame) both protocols behave in a similar manner in terms of throughput and delay. *Hence for T=20, E-FS-ALOHA outperforms FS-ALOHA for both throughput and delay.*

4.2 Discussion

The simulation results presented in previous section show that the optimum values of (S, N) (combinations of S and N that give best results in terms of throughput and delay) in E-FS-ALOHA suffer a shift towards higher values of S and lower values of N as compared to FS-ALOHA This is quite reasonable as, via permission given to an additional TS to attempt in the S slots together with new requests, there will be more transmission attempts in the S slots than in original FS-ALOHA

With optimum values of (S, N) for E-FS-ALOHA, we get improvement in throughput over S period as compared to throughput over S period for FS-ALOHA for same values of (S, N) (for example with (S, N)=(7, 3) and for a load of 8 req/frame, throughput over S slots for E-FS-ALOHA and FS-ALOHA are 35.3% and 29.6% respectively), but at the same time we lose throughput over N period as compared to FS-ALOHA (for example with (S, N)=(7, 3) and for a load of 8 req/frame, throughput over N period for E-FS-ALOHA and FS-ALOHA are 39.8% and 41 9% respectively). The order by which we get improvement in throughput over S period is greater than the order by which we lose throughput in N period. For example with (S, N)=(7, 3), and for a load of 8 req/frame, for E-FS-ALOHA, the improvement obtained in throughput over S period is double than the loss in throughput over N period. In E-FS-ALOHA with optimum values

of (S, N), we get improvement in throughput over longer period, as compared to FS-ALOHA and contribution of throughput over S period is more than the contribution of throughput over N period to the overall throughput (because S > N and T=S+N), hence we get overall improvement in throughput.

Since on the average more number of requests are getting through (as predicted by the improvement in throughput for E-FS-ALOHA as compared to FS-ALOHA), we get low mean delay for E-FS-ALOHA as compared to FS-ALOHA. Over the same period of T slots, in E-FS-ALOHA two TSs are allowed to served at a time together with new requests as compared to only one TS with new requests in FS-ALOHA, hence capacity requests experience less access delay on the average for E-FS-ALOHA as compared to FS-ALOHA.

Table 4.1 : Comparison of throughput achieved over S, N and T slots for E-FS-ALOHA and FS-ALOHA (T=6)

Load (req/frame)	(S, N)	Throughput over S period		Throughput over N period		Overall Throughput	
		FS-ALOHA	E-FS-ALOHA	FS-ALOHA	E-FS-ALOHA	FS-ALOHA	E-FS-ALOHA
4	(4, 2)	0.305	0.349	0.406	0.397	0.340	0.365
4	(3, 3)	0.359	0.345	0.422	0.405	0.391	0.375
4	(2, 4)	0.367	0.269	0.388	0.361	0.381	0.330

Table 4.2 : Comparison of throughput achieved over S, N and T slots for E-FS-ALOHA and FS-ALOHA (T=10)

Load (req/frame)	(S, N)	Throughput over S period		Throughput over N period		Overall Throughput	
		FS-ALOHA	E-FS-ALOHA	FS-ALOHA	E-FS-ALOHA	FS-ALOHA	E-FS-ALOHA
8	(7, 3)	0.296	0.353	0.419	0.398	0.333	0.366
8	(6, 4)	0.326	0.363	0.385	0.364	0.349	0.363
8	(5, 5)	0.349	0.361	0.349	0.325	0.349	0.343
8	(4, 6)	0.364	0.343	0.319	0.292	0.337	0.313
8	(3, 7)	0.369	0.304	0.293	0.264	0.316	0.286

Table 4.3 : Comparison of throughput achieved over S, N and T slots for E-FS-ALOHA and FS-ALOHA (T=20)

Load (req/frame)	(S, N)	Throughput over S period		Throughput over N period		Overall Throughput	
		FS-ALOHA	E-FS-ALOHA	FS-ALOHA	E-FS-ALOHA	FS-ALOHA	E-FS-ALOHA
15	(15, 5)	0.258	0.329	0 349	0 328	0.286	0.329
15	(14, 6)	0 272	0 340	0 319	0 299	0.286	0 328
15	(13, 7)	0.285	0.350	0 293	0 273	0.287	0.322
15	(12, 8)	0.297	0.356	0.271	0.250	0.287	0.314
15	(11, 9)	0.368	0.361	0 253	0 232	0.283	0 303
15	(10, 10)	0 320	0.364	0 237	0 216	0.278	0 290
15	(9, 11)	0.331	0.366	0 223	0 202	0 271	0 276
15	(8, 12)	0 342	0.365	0 211	0 190	0.263	0 260
15	(7, 13)	0.352	0.361	0 200	0 179	0 253	0 243
15	(6, 14)	0 360	0.353	0 190	0.169	0.241	0.224
15	(5, 15)	0 367	0 338	0 181	0.160	0.228	0.204

Chapter 5

Conclusions and Future Work

5.1 Conclusions

In this thesis work we have presented a Contention Resolution Algorithm called E-FS-ALOHA which is based on the original FS-ALOHA algorithm. E-FS-ALOHA is well suited for reservation based MAC protocols where certain amount of slots per frame are used for contention resolution E-FS-ALOHA is more attractive than FS-ALOHA for WATM networks because of its excellent delay performance, which is a major concern for the QoS oriented networks like WATM.

We can summarize the advantages of the proposed E-FS-ALOHA algorithm in terms of

- *Simplicity*: as its associated computation complexity is comparable to that of FS-ALOHA
- *Good delay response*. the mean delay of the proposed scheme largely improves form those obtainable with FS-ALOHA. It allows a better meeting of the QoS guarantees.
- *More maximum attainable throughput* (with increasing values of total contention slots T). as compared to FS-ALOHA, it provides better throughput while maintaining the throughput stability of the FS-ALOHA (i.e even during highly congested period the throughput of E-FS-ALOHA and FS-ALOHA do not significantly decrease from their maximum value as with slotted ALOHA).

- *No additional bandwidth* is required, as its operation does not require introduction of new systems parameters etc
- *No load dependent mechanism* is employed In practice correct estimation of traffic load is difficult

Generally, Contention Resolution Algorithm is implemented with Scheduling Algorithm (also called Bandwidth Allocation Algorithm) to constitute a MAC protocol As in a MAC frame, certain number of slots are allocated to a contention period and certain number of slots to data transmission period, there is always a decision that has to be taken about the number of slots which are allocated to each period. In some protocols this decision is dynamic (dynamic allocation), i.e number of slots allocated to each period is decided on per frame basis and in some cases number of contention slots and data transmission slots are fixed (static allocation) In dynamic allocation number of slots allocated to each period can decrease/increase depending upon channel load but this also means informing the Mobile Terminals about the boundaries in each successive frame. Having fixed number of slots saves this information transfer though at the cost of flexibility

The overall throughput of the MAC protocol in not determined by the throughput of the Contention Resolution Algorithm alone, but Quality of Service is highly dependent on the delay encountered by the capacity requests during contention cycle *Improvements obtained with E-FS-ALOHA as regards both the delay performance and throughput and its maintaining the throughput stability of the original FS-ALOHA are remarkable*. Also as the benefits of E-FS-ALOHA are with increasing vales of T (T=20, 30,...), it is more attractive for implementation in real situation than FS-ALOHA If average value of frame length lies between 80 and 100 slots, having 20-30 minislots (equivalently 10-15 slots, assuming one slot accommodate 2 minislots) devoted to contention period would be a reasonable choice, as indicated by the several existing MAC protocols for WATM, such as [17], in which a maximum of 32 minislots are devoted to contention period in the uplink frame of total length 80 slots, assuming one slots accommodates 4 minislots

5.2 Future Work

Following issues may be considered for further study

- E-FS-ALOHA can be integrated with a suitable Bandwidth Allocation Algorithm to work together as an appropriate MAC protocol for WATM.
- Some priority scheme for different traffic classes of ATM, (real time connections like CBR and rt-VBR sources and non real time connections like nrt-VBR, ABR, UBR sources) can be implemented with E-FS-ALOHA to give priority to real time sources to access contention period. In this way the access delay experienced by the real time sources on contention period can be further reduced resulting in better QoS for these types of sources. Also the effect of added priority scheme on the delay performance of non-real time sources should be analyzed.
- E-FS-ALOHA is a static scheme with fixed number of contention slots per frame It can be made dynamic by changing the number of contention slots according to estimated load on the network Its performance can be compared with the widely implemented splitting algorithms, which are dynamic in nature

References

[1] D Petras, "Medium Access Control Protocol for Transparent ATM Access in MBS," RACE Mobile Telecommunication Summit, Cascais, Portugal, November 1995

[2] J Mikkonen, J Aldis, G. Awater, A. Lunn, and D. Hutchinson, "The Magic Wand-Function Overview," IEEE Journal on Selected Areas in Communications, vol 16, no. 6, pp.953-972, August 1998

[3] J G Kim, I. Widjaja, "PRMA/DA. A New Media Access Control Protocol for Wireless ATM," IEEE ICC, vol 1,pp. 240-244, 1996.

[4] S. Jain, V. Sharma, D. Sanghi, "FAFS. A New MAC Protocol for Wireless ATM," IEEE ICPWC, pp. 135-139, Jaipur, India, February 1999.

[5] Vazquez-Cortizo D , García J , Blondia C , Van Houdt B., "FIFO by Sets ALOHA (FS-ALOHA): a Collision Resolution Algorithm for the Contention Channel in Wireless ATM Systems," Performance Evaluation, vol 36/37, pp. 401-427, 1999

[6] D. Raychaudhuri *et al.*, "WATMnet: A Prototype Wireless ATM System for Multimedia Personal Communication," IEEE Journal on Selected Areas in Communications, vol 15, no 1, pp 83-95, January 1997.

[7] N Abramson, "Development of the ALOHANET," IEEE Transaction on Information Theory, vol. IT-31, no. 2, pp 119-123, March 1985

[8] D Bertsekas and R Gallager, Data Networks, 2nd edition, Prentice Hall, 1992

[9] J Capetanakis, "Tree Algorithms for Packet Broadcasts Networks," IEEE Transaction on Information Theory, vol. IT-25, no 5, pp.319-329, September 1979.

[10] ETSI, "High Performance Radio LAN (HIPERLAN Type 2) Requirements and Architectures for Wireless Broadband Access," TTR 101 031, April 1997

[11] ETSI, "High Performance Radio LAN (HIPERLAN Type 2) System overview," TR 101 683, October 1996

[12] B Walke *et al.*, "Wireless ATM Air Interface and Network Protocols of the Mobile Broadband System," IEEE Personal Communication, pp 50-56, August 1996

[13] D Petras and U Vornefeld, "Joint Performance of DSA++ MAC protocol and SR/D-ARQ protocol for Wireless ATM under Realistic Traffic and Channel Models," Computer Networks, vol 31, pp. 903-918, 1999

[14] WAND Project Public Deliverable 3D4. Report. Wireless ATM MAC performance results. [Online] Available. http //www tik ee ethz ch/~wand/docs

[15] W W Lu, "An Efficient Medium Access Control for Wireless ATM," in Proceedings IEEE GLOBECOM'96, London, U K , November 1996

[16] C. Ecvi, "AWACS ATM Wireless Access System Potential Candidate for European HIPERLAN Standard," in Proceedings wmATM'98, China, pp. 175-185, April 1998

[17] D Petras and A Kramling , "Fast Collision Resolution in Wireless ATM Networks," In 2nd MATHMOD, Vienna, Austria, Feb 1997

[18] J.F. Frigon and V.C.M. Leung, "A Pseudo Bayesian Aloha Algorithm with Mixed Priorities for Wireless ATM," in Proceedings PIMRC'98, Boston, MA, Sept 1998

[19] K Pahlavan and A. Levesque., Wireless Information Networks, John Wiley & Sons, 1995.

[20] N Passas, S. Paskalis, D. Vali, and Lazaros Merakos, "Quality-of-Service-Oriented Medium Access Contol for Wiireless ATM Nerworks," IEEE Communications Magazine, vol 35, pp 42-50, November 1997.

[21] O Kubbar and H Mouftah, "Multiple Access Control Protocols for Wireless ATM: Problems Definition and Design Objectives," IEEE Communication Magazine, vol 35, pp 93-99, November 1997

[22] L Musumeci, P Giacomazzi, and L Fratta, "Polling-and Contention-Based Schemes for TDMA-TDD Access to Wireless ATM Networks," IEEE Journal on Selected Areas in Communications, vol 18, no 9, pp.1597-1607, September 2000.

[23] A. Tanenbaum, Computer Networks, Prentice-Hall, 1989